TECHNICAL GUIDANCE MANUAL

Climate Risk Assessment:
Technical Guidance Manual for DoD Installations and Built Environment

SERDP Project RC-2204

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14. ABSTRACT
This research presents and demonstrates a framework for assessing climate change risks to DoD installations and the built environment. The approach, which we call "decision-scaling," reveals the core sensitivity of DoD installations to climate change. It is designed to illuminate the sensitivity of installations and their supporting infrastructure systems, including water and energy, to climate changes and other uncertainties without dependence on climate change projections. In this way the analysis and results remain unclouded by the many choices and trade-offs required in the processing of projections from general circulation models (GCMs, also known as global climate models) and their associated uncertainties. The engine of analysis is the "climate stress test" which is an algorithm designed to stress the target system using systematic and exhaustive exploration of possible climate changes. Climate projections, including simulations from the NARCCAP are then used to inform the level of concern associated with each risk after the risks are identified via the climate stress test. The decision framework was applied to four sectors: water supply, energy costs, training and fire management and evaluated through piloting at four installations. The results show clear answers regarding the climate risks at each installation in each of these sectors, in terms that are quantifiably comparable across sectors. The expectation is the framework and assessment products are appropriate for application to all DoD installations and represent the very best approach for evaluating climate risks.

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Climate change, Risk Assessment, Decision Analysis, Adaptation, Water Supply, Fire Risk, Training, Energy Planning, Downscaling

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ACRONYMS

ACF	Apalachicola-Chattahoochee-Flint river basin
ANOVA	Analysis of variance
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
CF	Change Factor
CLM	The Community Land Model
CMIP3	Phase 3 of the Coupled Model Intercomparison Project
CMIP5	Phase 5 of the Coupled Model Intercomparison Project
Defra	UK Government's Department for Environment Food and Rural Affairs
EIRR	Economic Internal Rate of Return
GCM	General Circulation Model
IGDT	Information-Gap Decision Theory
IPCC	Intergovernmental Panel on Climate Change
KNN	K-Nearest-Neighbor Analysis
NCAR	The National Center for Atmospheric Research
NWS	The National Weather Service
P	Precipitation
PDF	Probability Density Function
PI	Performance Indicator
PRMS	The Precipitation-Runoff Modeling System
Q	Runoff/Streamflow
R	Open-Source Software for Statistical Computing and Graphics
RCP	Representative Concentration Pathways
RDM	Robust Decision Making
RO	Multi-Objective Robust Optimization
SEI	Stockholm Environment Institute
SRES	Special Report on Emissions Scenarios
SWAT	The Soil and Water Assessment Tool
T	Temperature
TTL	Task Team Leader
UKCIP	United Kingdom Climate Impacts Program
UNDP	United Nations Development Program
USAID	United States Agency for International Development
USGS	United States Geological Service
VBA	Visual Basic for Applications (programming language)
VIC	The Variable Infiltration Capacity hydrologic model
WARM	Wavelet Autoregressive Model
WATBAL	Water Balance, the hydrologic modeling component of WEAP
WEAP	Water Evaluation and Planning water system modeling software
WRI	World Resources Institute

1. INTRODUCTION

Executive Order No. 13653 requires the federal government to assess climate risks to its activities. Without guidance, however, the Department of Defense faces two undesirable but very possible outcomes: lack of compliance with the Executive Order or vast sums of financial and human resources misspent on widely varied climate studies that do not provide insight to risks. Without guidance, each installation or command might commission their own studies, producing results that are difficult to interpret and compare due to the wide variety of approaches that might be employed, many of which are ineffective. At this time there is no accepted general methodology for assessing the significance of climate risks to military installations. The premise that this document is based on is that a uniform framework for analysis of climate risks can short circuit the potential hazards of multiple climate impact assessment approaches and delays in compliance with the executive order.

The goal of this document is to outline a pragmatic process for climate risk assessment appropriate for application to military installations. The approach presented here is a robustness-based, bottom-up approach that makes the best use of available climate information but is not contingent on assumptions about future climate, or dependent on local climate modeling efforts. This document formalizes the methodology that was developed and demonstrated in SERDP RC-2204: Decision Scaling: A decision framework for DOD climate risk assessment and adaptation planning. In addition, elements of Capability-Based Planning and existing National Environmental Policy Act (NEPA) compliance protocols are incorporated for consistency with DoD planning methods. The methodology is presented in general terms and serves as an analytical framework that can be further developed for wide application or tailored for specific applications.

Though considerable investment has been made in climate modeling and downscaling of GCMs with hoped-for benefit to decision makers, the results of that modeling effort have not been effectively incorporated into climate risk assessment or adaptation planning. For example, a recent study of the World Bank's Independent Evaluation Group [IEG, 2012] found that "climate models have been more useful for setting context than for informing investment and policy choices" and "they often have relatively low value-added for many of the applications described." The lack of success in the use of climate projections to inform decisions is not due to lack of effort in translating model outputs to be relevant to decision makers. Instead, there are two fundamental and unavoidable issues that limit the utility of these approaches. First, the uncertainty associated with future climate is largely irreducible in the temporal and spatial scales that are relevant to military installations. As a result, climate science-led efforts do not typically reduce the uncertainty of future climate, and in fact, are unlikely to describe the limits of the range of possible climate changes. Perhaps most important, climate projections have the least skill in the variables that are most important from the perspective of risk, such as hydrologic extremes (e.g., floods and drought) and temperature extremes. Often, the results of a climate change analysis present a wide range of possible future mean climates, no insight on climate extremes, and the sense that this is only the tip of the iceberg for climate uncertainty.

As a result, the goal of narrowing the range of future uncertainties is not achieved. Instead, a framework focused on accepting and addressing uncertainty, rather than reducing it, is needed.

The second issue is that efforts that focus on projection of future climate fail to address the critical issue of how to use that information to improve decisions. At present, military planners are ill-equipped to 1) incorporate climate information and all its uncertainties within a broader assessment of an installation's risks over a changing future, and 2) make insightful recommendations for adaptation measures to address risks to mission or installation. In the typical engagement with science, the scientific analysis reduces uncertainty and identifies a likely future, whereupon the planner can select the best options for that future. However, given that climate science is not in the position to present a likely future of limited and reasonable range, a different approach is needed to assess risks and plan for future adaptation to climate change. This document describes such an approach.

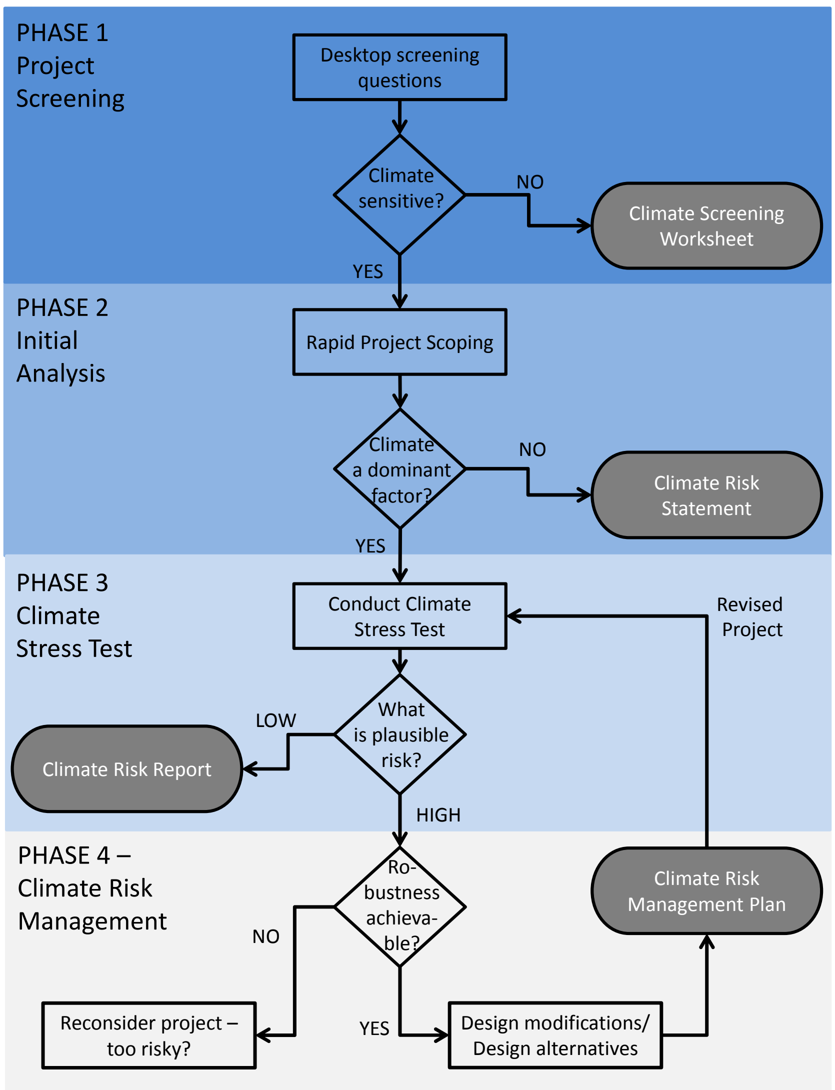

Figure 1. Decision tree schematic providing overview of the decision flow.

The **climate risk assessment** framework presented here is based on the analysis method known as "decision-scaling." Decision-scaling is a bottom-up, robustness-based approach to climate risk assessment and management (Brown et al., 2011) and was applied to military installations in RC-2204. This guide uses the insights from that research and formalizes an approach to implement them. The approach focuses on understanding vulnerabilities of the system rather than focusing on forecasting future climate. In this book, the term "system" or "activity" refers to object of analysis, and can be a military installation, a military activity, or a utility system supporting an installation. The analysis method is designed to be comprehensive and exhaustive in recognition of the tendency of the human mind to overlook risks of low probability events, and thus be vulnerable to surprise.

The framework is founded on a deep knowledge of climate science and the strengths and limitations of available climate data products. However, it also leverages existing approaches used in DoD to address environmental regulatory compliance and planning under uncertainty, namely NEPA compliance and Capability-Based Planning (CBP) It shares a clear work flow to increasingly sophisticated analysis methods, triggered by findings of previous stages, with NEPA. With CBP it shares the concepts of using a range of scenarios to "stress test" an activity, although the application here is used to identify vulnerabilities rather than identify specific capability needs.

Decision-scaling features prominently in both the risk assessment aspects and general structure of the climate risk assessment methodology because it is efficient, scientifically defensible (i.e., does not involve numerous *a priori* assumptions about the future, and does not rely on GCMs for direct climate input), and because it makes the best use of the available climate information, which is typically highly uncertain, but may still be useful under particular conditions. It creates those conditions by first identifying the specific vulnerabilities of a system, using that information to describe *ex post* scenarios of the conditions that cause vulnerabilities, and then applying the best available climate information to describe the level of concern associated with a specific vulnerability.

The process for assessment of climate risks is shown in Figure 1. The process is hierarchical with different phases or stages of analysis triggered based on the findings of the previous stage. Thus it functions as a "decision work flow." The framework leads the analyst to the appropriate level of analysis based on the findings of each stage. The approach is designed to be economical in terms of effort and resources. The procedure consists of four successive stages: Stage 1 Installation Screening; Stage 2 Climate Sensitivity Test; Stage 3 Climate Risk Assessment; and Stage 4 Climate Risk Management. Each stage increases in the level of analysis with effort that is proportionate to the need. In this way it follows the example of policies implemented for compliance with the NEPA, where levels of analysis indicated by aspects of a particular project (e.g., Categorical Exclusion, Environmental Assessment, Environmental Impact Statement). Here, Stage 4 is an optional step, as the primary focus is climate risk assessment.

The **climate risk assessment framework** presented in this paper represents an implementation of the general decision-scaling methodology designed for the specific needs of military planners. In addition to addressing the fundamental science issues, it is designed with the economic use of human and financial resources in mind. The process is informed by the “Decision Tree” approach that the authors developed to assessing climate risks to infrastructure projects (Ray and Brown, 2015). That process, which is garnering great interest in the World Bank, also features four stages of similar analysis as presented here.

The focus of this document is climate risk assessment. However, the methodology leads directly to climate risk management and that process is introduced in Stage 4. Climate risk management requires a systematic approach to planning under climate change uncertainty. In this document we highlight a method for doing this but the specific details are beyond the scope of this guidance document. The method involves aspects of decision analysis, benefit cost analysis and capability-based planning to guide the analyst to an effective strategy for managing significant climate risks that were identified in the risk assessment process. Aspects of other tools for decision making under uncertainty, such as Robust Decision Making (RDM), stochastic/robust optimization (including real options analysis), or Info-Gap Decision Theory (IGDT) could also be integrated with the framework to enhance its capabilities in risk management. An overview of methods are described later.

At present the DoD has been tasked with evaluating climate risks to its installation and operations but the guidance for doing so has not been specified. There is clear need to provide guidance for doing so and a risk that a great deal of resources will be poorly spent without such guidance. There is additional real concern that climate risks are not identified and managed due to poor analysis methods. This document describes a scientifically defensible, repeatable, direct and clear method for evaluating installations to climate change. At the conclusion of the process, the military planner will be empowered to confidently communicate the method by which the vulnerabilities of the project have been carefully assessed, and how the adjustments that were made (if they were necessary) improved the installation’s ability to withstand the climate risks of the future.

2. BACKGROUND

The **Climate Risk Assessment Framework (CRAF)** presented here is based on the basic principles of bottom-up climate risk assessment methodologies, such as developed in decision-scaling (Brown et al., 2011) and Robust Decision Making (Popper et al., 2009), for the specific needs of those interested in conducting climate risk assessments of infrastructure and operations. In the preparation of this approach, other existing decision support tools were reviewed, including products produced by the United Kingdom Climate Impacts Programme (UKCIP), the World Bank Climate Change Group (CCG), the United States Agency for International Development (USAID), and the World Resources Institute (WRI). Insights from this review were incorporated into the design of this tool.

While conceptually the risks of climate change appear important, there is no accepted general methodology for assessing the significance of climate risks to infrastructure or societal activities at any particular location. Further, despite a clear mandate to assess climate change risks, there is no accepted process within the DoD. The goal of this document is to outline a pragmatic process for risk assessment of DoD installations that serves as the basis for development of more tailored frameworks applicable to the wide range of military considerations. This section briefly reviews theoretical considerations that provide the basis for an effective climate risk assessment framework.

The **climate risk assessment framework** described in this paper is based on the growing consensus that robustness-based approaches are needed to address uncertainty, and its potential impacts on infrastructure planning [*Wilby and Dessai*, 2010]. These approaches emphasize assessment of individual systems and their vulnerabilities and to seek solutions to those vulnerabilities in terms of robustness, or their ability to perform well over a wide range of future uncertainty, including climate and other uncertainties [*Brown and Wilby,* 2012; *Hallegatte et al.*, 2012; *Prudhomme et al.*, 2010]. Together, they represent an alternative philosophy to the most prominent approach to climate risk assessment, so called "top down" approaches, which emphasize the pursuit of further knowledge of future climate conditions, typically focusing effort on climate projections downscaled from time-series of General Circulation Models (GCMs, also known as global climate models) and then assess the system response under a limited set of plausible future climate and demographic/land use conditions.

Considerable investment has been made in climate modeling and downscaling with hoped-for benefit to decision makers. However, that investment has not been effectively incorporated into climate risk assessment or adaptation efforts. As a result, the benefits to decision makes have not been achieved. For example, a recent study of the World Bank's Independent Evaluation Group [*IEG*, 2012] found that "climate models have been more useful for setting context than for informing investment and policy choices" and "they often have relatively low value-added for many of the applications described."

The lack of success in the use of climate projections to inform decisions is not due to lack of effort in translating model outputs to be relevant to decision makers. Instead, there are two fundamental and unavoidable issues that limit the utility of these approaches. The first problem is that the uncertainty associated with future climate is largely irreducible in the temporal and spatial scales that are relevant to risk assessment and adaptation planning [*Stainforth et al.*, 2007a]. Military installations and most activities operate at local scales, on the order of tens of kilometers. In addition, typically planning horizons may be 50 years or less. At these spatial and temporal scales the chaotic nature of the earth's climate system is dominant. This makes it extremely difficult for climate modeling efforts to provide insights that are relevant. Even the most advanced downscaling techniques, including dynamical downscaling using regional climate models, will provide only a partial glimpse, and possibly biased glimpse, of the changes that might be experienced at these scales.

Climate projections provide limited and often biased explorations of the effects of internal climate variability, especially precipitation variability [*Rocheta et al.,* 2014], with amplified errors for extremes [*Fekete et al.,* 2004]. As a result, climate science-led efforts do not typically reduce the uncertainty of future climate for risk assessment or planning purposes, and in fact, are unlikely to describe the limits of the range of possible climate changes. Nor are they able to provide probabilistic representations of the uncertainty [*Hall,* 2007]. Because risk is a function of both probability and impact [*Dessai and Hulme,* 2004], the inability of climate projections to probabilistically represent uncertainty is a substantial obstruction to the assessment of climate-related risks. Perhaps most important, climate projections have the least skill in the variables that are most important, such as precipitation variability and extremes (e.g., flood and drought). Those extreme events are located at the tails of distributions of climate variables and are expected to change more rapidly than the mean in a changing climate [*Dai et al.,* 1998]. Often, the results of a climate change analysis present a wide range of possible future mean climates, no insight on climate extremes, and the sense that this is only the tip of the iceberg for climate uncertainty.

The second problem is that climate modeling efforts are not designed to provide useful information at the scales relevant to assessing climate risks to military installations. The climate modeling experiments are designed primarily to provide greater insight on the earth's climate system under alternative scenarios of carbon emissions. The use of the same climate simulations for aiding risk assessments at local scales is convenient by requires careful reconsideration of their utility and their best use for information decisions.

Some have suggested that the magnitude of the effects of changes in climate might be small relative to changes in other variables such as population, technology, and demand over medium to long-range time periods [e.g., *Frederick and Major,* 1997; *Lins and Stakhiv,* 1998], some have suggested that climate change may be the factor of greatest importance to long range planning [e.g., Arnell and Lloyd-Hughes, 2014; Rockstrom et al., 2009], and still others have argued that the relative likelihoods of long-range change magnitudes are not quantifiable from our present limited perspective [e.g., *Allen et al.*, 2001; *Lempert et al.*, 2004]. This range of opinions leads to a lack of consensus on ways to assess climate risks and plan effective adaptation. In fact, the most prominent guidance on adapting to climate change emphasizes "flexibility" and the idea of "no regrets," meaning actions that are taken are beneficial whether climate change occurs as expected or not. These facts illustrate the lack of a framework for incorporating insights from climate science into climate risk assessment or adaptation planning.

Consequently, military planners are ill-equipped to 1) incorporate climate information and all its uncertainties into a risk assessment for an installation or activity, and 2) make insightful recommendations to reduce vulnerabilities to possible problematic climate changes. In the typical engagement with science, the scientific analysis reduces uncertainty and identifies a likely future, whereupon the planner can select the best options for that future. However, given that climate science is not in the position to present a likely future of limited and reasonable range, a different approach to climate risk assessment and management is needed.

The **climate risk assessment framework (CRAF)** is designed to address these fundamental issues to provide a path forward for military planners who seek to identify risks posed by climate change. In addition to addressing the fundamental science issues described above, it is also designed with the economic use of human and financial resources in mind. Military installations and operations are diverse, and inevitably specific applications will require tailored approaches. The goal of this work it develop a general framework that can guide the tailoring of specific applications. The framework employs a hierarchical design to allocate climate-risk assessment effort in a way that is consistent with each system's potential sensitivity to that climate risk. The process includes four potential levels of analysis with different stages of analysis triggered based on the findings of the previous stage. The result is different categories of systems undergo different degrees of analysis with effort that is proportionate to the need. The process is an implementation of a bottom up, climate informed decision analysis (see Box 1).

BOX 1 – BOTTOM-UP CLIMATE INFORMED DECISION MAKING

The term "bottom-up," as adopted in this report, refers both to the emphasis on the identification of system vulnerabilities through multi-dimensional sensitivity analysis and *ex post* scenario development that incorporates climate projection information from GCMs – see Box 2), and the active involvement of stakeholders in the process.

The evolution to bottom-up, vulnerability-based analysis may be analogous in some respects to DoD's Capability-Based Planning. CBP is rooted in the concept that with the fall of the Soviet Union, military planning could not focus on a single or small set of most likely enemies.

Instead, the general capabilities of a generic enemy should be considered and planning would be responsive to those capabilities. A critique of CBP is that the vague description of the enemy threat leads to generic strategies there were impractical to implement. That shares a critique of current climate change adaptation guidance, which states, given the uncertainties, plans should be flexible and feature “no regrets” responses to climate change. However, such approaches are similarly impractical.

The CRAF uses a similar embrace of indeterminism reflecting the irreducible uncertainties of climate change. Rather than spending resources to ascertain the best guess future climate, which is not very likely to be correct, the framework seeks to identify vulnerabilities by stress testing activities with a wide range of plausible climate changes to reveal weaknesses. However, at this point it differs with CBP by then focusing analysis on those specific vulnerabilities, assessing their probability of occurrence and developing possible solutions to manage the associated risk.

Building on the concepts, research findings and insights from RC-2204, this document provides a scientifically sound, repeatable, direct and clear method for identifying and evaluating installation risks due to climate change. At the conclusion of the process, the analyst will have a clear approach to ensure that climate risks were fully assessed, the level of concern assigned to any risks estimated, and, if necessary, describe how measures to address those risks were evaluated and validated. The document is intended to provide an overview of a framework that could be more fully developed and deployed within DoD.

3. THE CLIMATE RISK ASSESSMENT FRAMEWORK

This chapter presents the specific steps of the CRAF. The process is hierarchical, meaning that in each stage of the analysis, either the process ends because the climate risks have been adequately addressed or the process proceeds to the next stage of analysis to address remaining concerns. Stages 1 through 3 are elements of risk assessment. Stage 4 shifts to risk management. This section provides a detailed description of each of these stages in the methodology.

The overarching objective of the **framework** is to provide a consistent, credible and repeatable process for analysts to employ for assessing climate risks. It is designed to be economical in effort such that effort expended is proportional to the climate concerns of the system being investigated. In other words, the effort required to conduct the analysis increases if initial stages of analysis indicate that there are potential climate risks. This follows the approach used for NEPA compliance. The typical NEPA process involves a preliminary screening step that excludes many federal activities from further analysis (Categorical Exclusion), then proceeds to more intense analysis if the environmental concerns warrant it, from Environmental Assessment to the long and involved Environmental Impact Statement. The CRAF follows this logic, reserving full analysis for only those activities that have significant concerns related to the risks of climate change. Please note, however, that the analysis described in this framework would not approach the cost and complexity of NEPA compliance.

The CRAF is designed to be implemented internally or to be used as guidance for external consultants to follow. When outside expertise is needed, the tool provides clear guidance on the process that should be contracted for. Finally, the tool is expected to allow the analyst to feel confident that climate change risks have been assessed and addressed and for the larger stakeholder community to agree.

Figure 2 presents a schematic workflow of the framework. The procedure consists of four hierarchical stages: Stage 1 Project Screening; Stage 2 Initial Analysis; Stage 3 Climate Stress Test; and Stage 4 Climate Risk Management. The overarching goal of the **decision tree** framework is to enable the analyst to assess the performance of a system under a wide range of climate changes, identify problematic climate changes, if there are any, and then further investigate the problematic changes to assess their probability of occurrence.

The term "level of concern" is a substitute for a quantitative risk calculation in recognition of that subjectivity. The particular strength of the decision-scaling-based method presented in this report is its handling of climate-related uncertainty. Often climate risk assessment and adaptation planning is impeded by the uncertainty associated with projections of future climate change. The framework guides the analyst through a process that overcomes this impediment by reserving the use of climate projections to the final stages of analysis, when levels of concern are assessed, rather than using them as a starting point.

Stage 1 consists of a well-defined, self-guided desktop screening of the system of interest conducted with the assistance of directed questions, a climate screening worksheet. The analyst would execute Stage 1 with little need for expert consultation. Systems that do not have significant climate sensitivities are identified using the process and are excused from further analysis. Systems with potentially significant climate sensitivities proceed to the next stage of analysis. The judgment regarding potential sensitivity is made by the analysts and facilitated by guiding questions.

Projects classified as climate-sensitive in Stage 1 move to Stage 2, which consists of a rapid project scoping exercise, during which it is necessary to build a first order approximate model of the system (if such a model does not already exist) and use judgment regarding an acceptable level of climate sensitivity. Though it cannot be considered a thorough climate change risk assessment, the rapid scoping exercise is used to estimate a system's relative sensitivity to climate changes and indicate whether a more in-depth climate change risk assessment is required.

For systems with climate sensitivities that are significant relative to other, non-climate, sources of performance sensitivities, a Stage 3 analysis is recommended. This step requires the use of a system specific analytical model or other representation of the system to assess the climate sensitivity of the system in quantitative terms. Stage 3 would likely be performed by a qualified team of specialists or expert consultants with knowledge of decision-scaling applications.

Stages 1, 2 and 3 include jump-out points for exit from the **decision tree**, to be used when the climate risks are deemed acceptable for the purpose of the analyst's evaluation. In the cases where significant and credible climate risk is identified, Stage 4 analysis is required. In this case, climate vulnerabilities that were identified in Stage 3 are addressed through the evaluation of possible adaptation, which can be designed and evaluated using tools for decision making under uncertainty. Methods for dealing with decision making uncertainty, and in some cases further geophysical analysis, are needed. Information on some of the options available for decision making under uncertainty is presented in an appendix.

An important innovation employed in this CRAF is the use of a bottom up, climate informed decision analytic approach. More information is given in Boxes 1 and 2.

BOX 2 – *A PRIORI* VS. *EX POST* SCENARIO DEVELOPMENT

A priori scenario development is the generation of scenarios from internally-consistent storylines of future conditions (including, but not limited, to demographic, economic, land use and climate). Water systems models using *a priori* scenarios, also referred to as the "scenario-led" approach, test the performance of the system across a sample of futures described by the storylines. *A priori* scenarios tend to refer to IPCC storylines and take climate inputs directly from GCMs.

Ex post scenario development is the generation of scenarios by parametrically or stochastically varying the climate (and other) data in order to identify vulnerabilities in water system performance, and elaborating scenarios according to the vulnerabilities of the project or by the optimality of decisions. Scenarios defined *ex post* are targeted at the identification of problematic system performance (in whatever future state that might occur), and are less likely to underestimate vulnerabilities. In addition, the *ex post* definition of scenarios may facilitate the assignment of relative or subjective probabilities to the scenarios. Because GCM projections do not enter *ex post* scenarios until the end of the analysis, *ex post* scenarios are less susceptible to the well-documented shortcomings of GCMs.

Each stage of analysis leads to a specific product which documents the analysis and for presentation to reviewers to demonstrate that climate risks have been assessed according to a DoD-approved procedure. For example, Stage 1 results in a completed worksheet, the Climate Screening Worksheet, demonstrating the climate sensitivity (or lack thereof) for a given system. Stage 4, when necessary, results in an in-depth report, the Climate Risk Management Plan, that outlines the climate risks and proposed means of addressing them. Each step is defined in greater detail below.

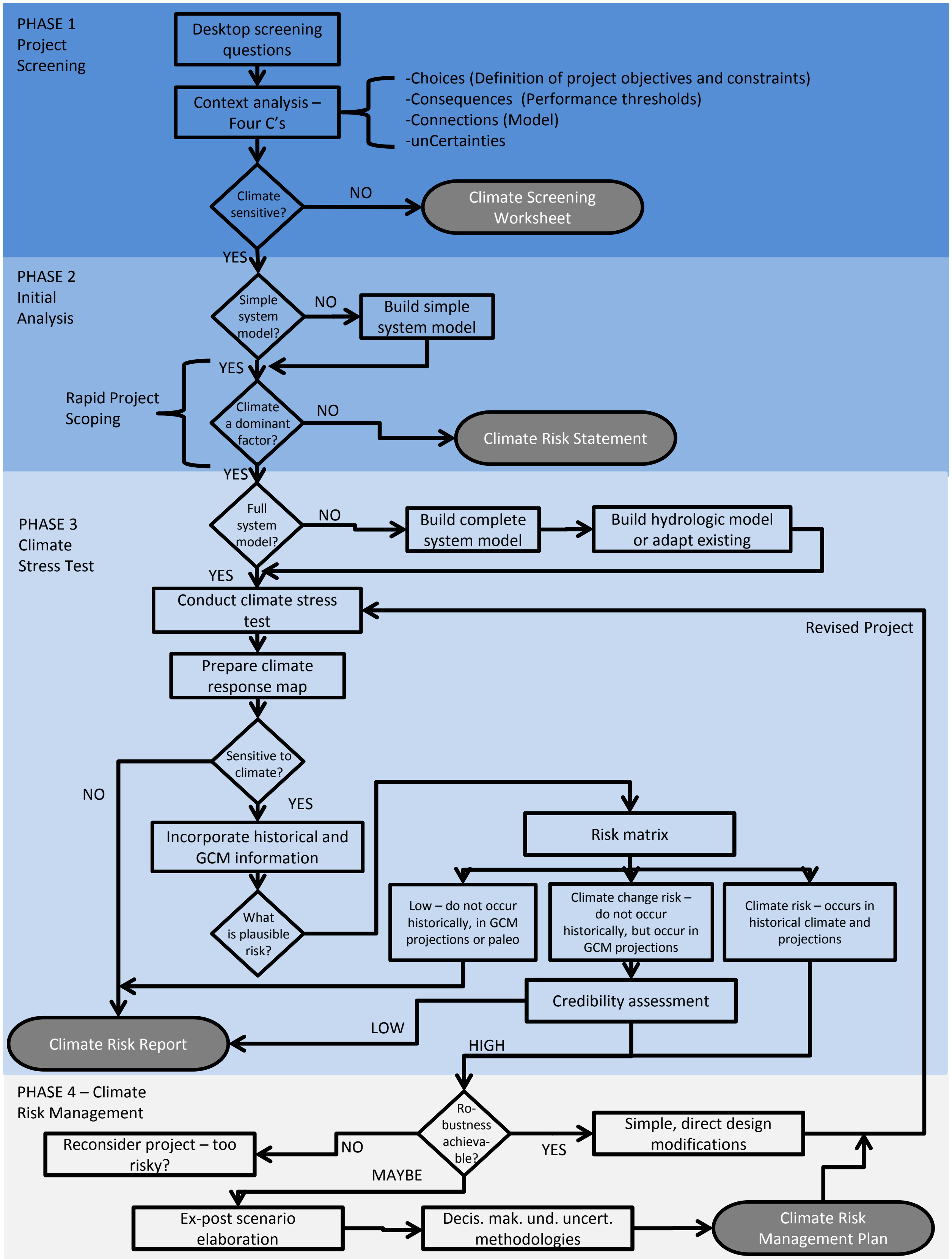

Figure 2. Climate Risk Assessment Framework decision flow

3.1. Stage 1: Climate Risk Screening

The climate risk screening process is used to quickly exclude the many activities that are very unlikely to be threatened by climate change or warrant further analysis due to the nature of the activity. A checklist of activities would be used by the analyst; upon finding an activity on the list, the climate risk screening would be complete with the completion of the checklist. Those activities not indicated to be excluded from analysis would proceed to Stage 2 analysis. The checklist should be created by a DoD or agency team or external consultants.

Primary considerations for automatically excluding activities from further analysis should include: 1) is the activity inherently insensitive to weather events, and thus climate change, or 2) is the activity inherently adaptable and does not need to consider long term changes. An example of the first would be the activities of the personnel office. An example of the second would be landscaping, which is sensitive to weather events but is inherently adaptable to changing conditions with short lifespans of any decisions and therefore little need to prepare for climate change before experiencing it. Indoor activities and systems with little exposure to weather and climate would be excluded from further analysis after Stage 1. In essence, Stage 1 is analogous to a Categorical Exclusion in NEPA parlance.

Product: Climate Risk Checklist – a standardized checklist that an analyst would use to document the fact that the activity either does or does not require further analysis. If the activity does require further analysis, i.e., is not specifically excluded by the checklist, it would proceed to Stage 2.

3.1.1. The Four C's

A key aspect of the Climate Screening Worksheet is the context analysis which defines the bounds of the system under evaluation. The context analysis is guided by a framework described as the Four C's: **Consequences, Connections, unCertainties and Choices,**. This mnemonic serves to establish better understanding of the system itself and the means by which climate risks might be addressed. For example, Consequences represent the results of a system being negatively impacted by climate change – would it be a temporary inconvenience or a mission damaging impact? Connections are the links between weather and climate and the system's ability to perform its function. Are there links, are they significant, are they severable? unCertainties are the external factors that affect the performance of the system. Climate is the prominent factor being assessed, but there may be other uncertain factors that make the lessen the significance of climate uncertainties. For example, underground water pipelines may be affected by climate in some minor ways but the age and material of pipes and the chemical properties of the water are likely more important factors than climate. Finally, Choices represent the decisions that could be made to address any problems that might arise. Identifying and evaluation choices is a part of the climate risk management process but realizing the degree to which a system can be adapted locally through autonomous decisions also helps understand the level of concern that climate change might pose for a system

3.1.2. Jump Out of the Decision Tree from Stage 1

If the Climate Screening Worksheet suggests that the system is of a type that has no meaningful climate sensitivities, then further climate risk assessment is not necessary. The analysis concludes with this finding as documented in the Climate Screening Worksheet.

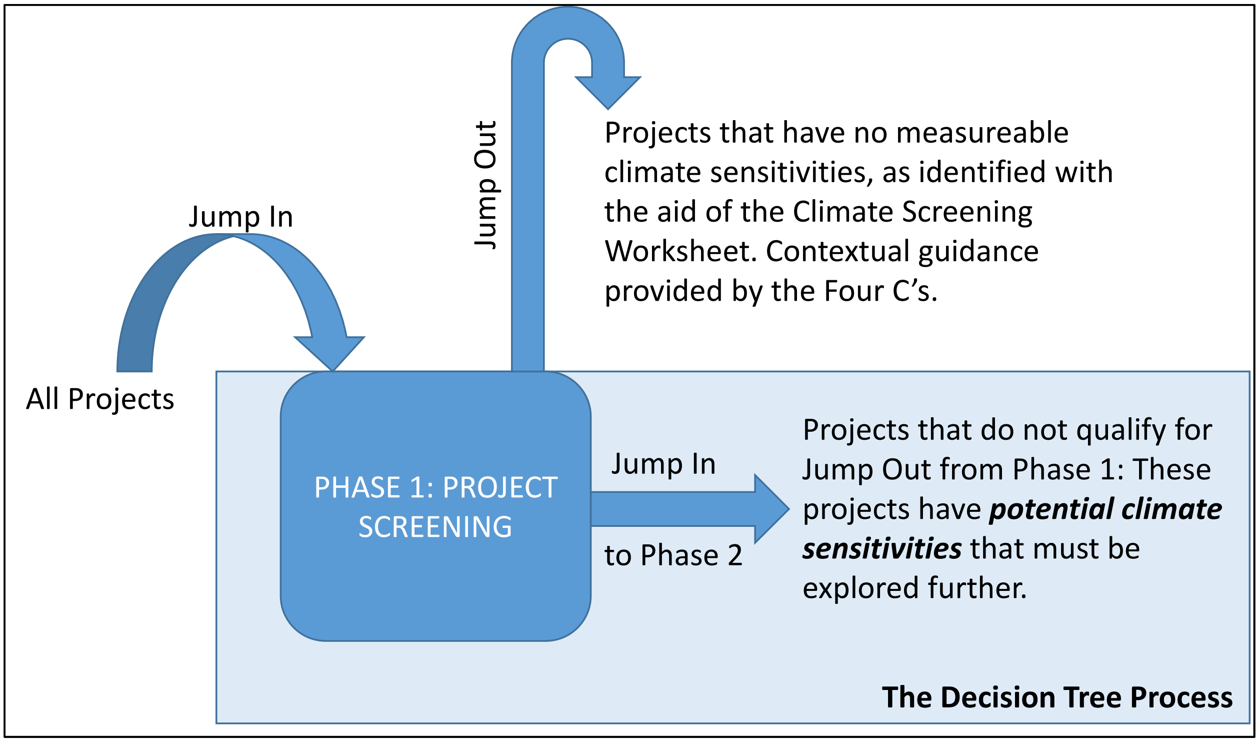

Figure 3. Stage 1 jump-in and jump-out conditions

3.2. Stage 2: Climate Sensitivity Test

The intention of Stage 2 is to explore the system further in terms of context, and to identify cases in which climate sensitivities are present, but where those climate sensitivities are unlikely to be important relative to sensitivities of other types. The analysis is largely qualitative in approach, consisting of a structured thought exercise performed by the analyst to answer the basic question of whether possible changes in climate pose a significant threat to the functioning of the system. This represents a key decision stage, as proceeding further in the climate risk assessment process involves engaging in technical analysis and likely seeking outside technical support. This step also recognizes that informed human judgment regarding the significance of risk is an unavoidable and powerful analytic approach.

The climate sensitivity test investigates the properties of a particular activity or system and the potential connections between that system and the effects of climate change. Two answers are sought as part of this process:

1) Does the activity have potential direct impacts from a changing climate?
2) If there are potential direct impacts, could those impacts be significant enough to warrant some kind of management actions or adaptation?

By answering these questions, the activity is classified into one of two categories: significantly climate-sensitive or not significantly climate-sensitive. The classification would be based on the answers to questions in a worksheet (to be developed) and complemented by the analyst's knowledge of the activity and plausible climate changes, and information about the installation, including historical climate extreme events. The history of extreme events need not be formal, but rather knowledge of presence or absence of extreme weather events historically, like droughts for floods, affecting the installation or specific activity is sufficient.

Examples of screening questions would include:

- Is this a water-related system?
- Does the activity take place outdoors?
- Are there examples of weather events affecting this system historically?
- Is this system potentially affected by sea level rise? Does it border an ocean?
- Is this system potentially affected by flooding? Is it located in or near a floodplain?
- Does this system utilize weather or climate information in planning its functions or activities?
- In your judgment, would an increase in temperature affect this activity?
- In your judgment, would an increase or decrease in average precipitation amounts affect this activity?
- Would any of the effects identified above have a significant impact on the ability of that activity to perform its mission?

The worksheet is designed to lead to a clear classification. In general, systems related to utilities, such as water and energy, would proceed to Stage 3, as would intense outdoors activities, like training. Roads, culverts, stormwater systems and similar infrastructure affected by temperature and precipitation would likely proceed to Stage 3.

The Stage 2 analysis is conceived to be accomplished by a single trained analyst. However, in many cases the analyst should seek guidance from specialists with good understanding of the specific system being investigated. Available climate information products can be accessed to provide background information on the possible ranges of climate changes that might be experienced (see Box 3).

The Stage 2 analysis relies on human judgment, aided by the guiding questions. To address the known systematic failings of human judgment, some awareness of “decision traps” is useful. The following analytic rubrics are designed to assist the analyst in answering the question described above. They are drawn from standard decision analytic practice and cognitive theory on common errors in human decision making under uncertainty. These considerations guide the analyst in the course of evaluating climate risks to the system of interest.

3.2.1. Importance of Time Frame

Climate change represents changes in the long term average weather conditions that occurs over many decades. At any location in the world, the natural variability of climate and weather is a much more dominant factor than climate change in the near term, for example, in the next 10-20 years. Therefore, any system that will not have a lifetime of more than 10 years is unlikely to be climate sensitive, even if it is sensitive to weather conditions generally. Likewise, if the system is automatically updated over short time spans, again, 10 years or less, then the system is unlikely to be exposed to significant climate risks.

3.2.2. Avoiding Common Decision Errors

The field of decision making under uncertainty has documented a number of common cognitive biases that can potentially impair the performance of a subjective decision making process. Luckily, being aware of these biases is a strong step in avoiding their negative impacts. These biases are:

- Recallability trap – this is a decision trap where we give undue weight to recent and prominent events. For example, people often fear flying due to their recall of major airline disasters despite facts that show it is a significantly safer mode of travel than driving. Similarly, emphasis on the negative consequences of drought in a particular location may cause an analyst to overlook the potential for future flood effects in that place.
- Overconfidence trap – this decision trap causes the analysts to overestimate the ability of forecasts to predict the future accurately. In the case of climate change, forecasts that the future may be drier could cause an analyst to overlook possible negative impacts of a wetter future, despite strong evidence that climate projections cannot rule out changes in either direction.

- Status quo trap – this decision trap leads us to expect that the status quo will continue, and that events that haven't previously occurred at a particular location cannot occur at that location. This is related to the example of the Black Swan, where people assumed swans could not be black because they had only seen white swans. Yet, there was no physical reason that swans could not be black, an indeed, in certain parts of the world they are.

Product: **Climate Screening Statement** – a standardized document with a series of questions which leads to the categorization of the system as either climate-sensitive (leading to Stage 2) or not climate-sensitive (leading to the end of the climate assessment process, and jump-out from Stage 1). Approximately 2 pages in length. The Climate Screening Worksheet forms the basis of the Climate Screening Statement and is completed regardless of project categorization (climate-sensitive or not). The Worksheet would be either submitted alone (as evidence of the climate-insensitivity of the system), or is included as part of more thorough climate risk report that results from Stage 3.

BOX 3 – *CLIMATE INFORMATION PRODUCTS*

There are a number of tools available that provide easy access to a range of climate information products. For example, the World Bank Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/index.cfm), and the Nature Conservancy's Climate Wizard (http://www.climatewizard.org/) are helpful tools for the quick identification of anticipated changes in temperature, precipitation, and other climate conditions relevant to the location of the planned water project. The UNDP's Adaptation Learning Mechanism (http://www.adaptationlearning.net/) offers geographically-targeted resources for climate change adaptation. If it is believed that the system is potentially sensitive to large decreases in precipitation, for example, then these resources for climate information are able to analyst concerning the range of precipitation changes in the region of interest, allowing consideration of climate risks relative to risks of other types.

If it is determined that sensitivity to climate is a significant factor in the expected performance of the project, then a more detailed model of the system's response to climate changes may be required. If the project cannot be excused from an in-depth climate stress test, then the now-intermediate Climate Risk Statement can be skipped as its content will be covered in the Stage 3 Climate Risk Report.

3.2.3. Jump In to Stage 2 from Stage 1

If the project is shown to have significant potential climate sensitivities through the qualitative assessment provided by the Climate Screening Worksheet, then the **decision tree** process proceeds from Stage 1 to Stage 2.

3.2.4. Jump Out of the Decision Tree from Stage 2

If Stage 2 of the **decision tree** shows that the project has climate sensitivities, but that those sensitivities are small relative to sensitivities to uncertain factors of other types (e.g., demographic or political factors), then further analysis is concluded not to be required and the process terminates after completion of the Climate Risk Statement..

Product: **Climate Risk Statement** – a document that outlines the effects of uncertainty on the system and the expected relative effect of climate uncertainty in comparison to other uncertainties. The statement would justify the reasoning that further climate analysis is not required, such as the lack of sensitivity of the system or lack of deterioration in performance below acceptable ranges. A template is provided for the completion of the statement. Less than 5 pages in length.

The Climate Risk Statement is completed only in the event of jump-out from Stage 2; otherwise the climate risks will be described as part of a more in-depth report on climate vulnerabilities (the Climate Risk Report of Stage 3 or the Climate Risk Management Plan of Stage 4).

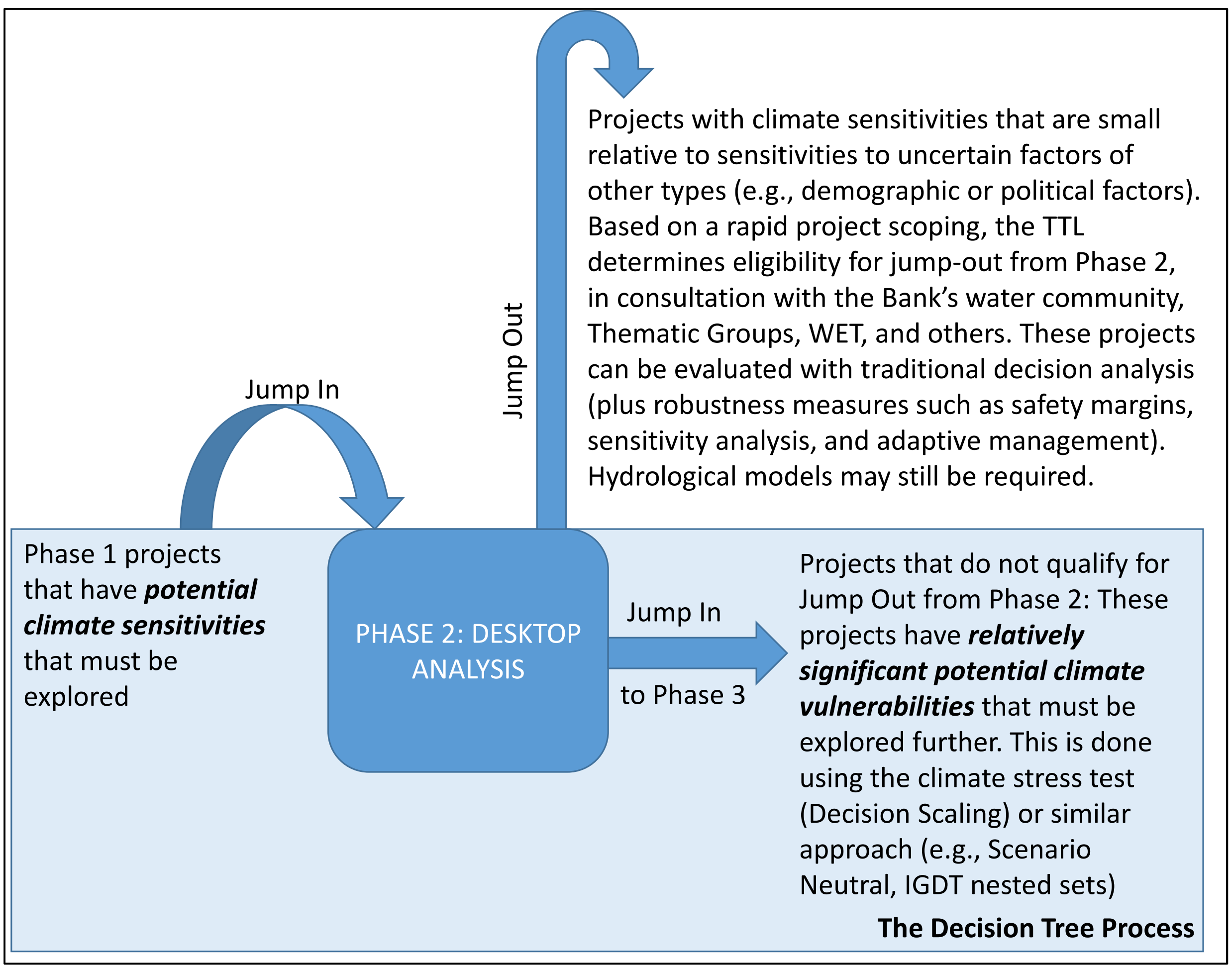

Figure 4. Stage 2 jump-in and jump-out conditions

3.3. Stage 3: Climate Stress Test

Proposed projects entering Stage 3 have climate-related potential vulnerabilities significant enough relative to other risks that they cannot be dismissed. Stage 3 is the point at which the climate concerns are prominent enough that more specialized quantitative analysis would be warranted. At this point, if a formal model of the natural, engineered or socio-economic system is not available, it must be created in order to relate climate conditions to the impacts on performance indicators identified in Stage 2. The third Stage of the **decision tree** is the first that is highly technical in nature and will require a trained specialist or an external expert consultant. Considerations must be given to data availability, cost and time constraints for the analysis. The overall approach of a climate stress test is shown in Box 4.

BOX 4 – GENERAL PROCEDURE FOR A CLIMATE STRESS TEST

First, a mathematical representation (model) of the activity that includes weather or climate inputs is created. In some cases, existing relationships or models can be used. For example, Work-Rest tables list the amount of training that can take place for different weather conditions. The relationships described in the table can be formalized using ordinary least squared regression. In other cases new models might need to be created, which will increase the effort needed to conduct the analysis. Further examples are illustrated in the RC-2204 final report.

Second, the weather or climate inputs to the model are varied systematically in ways that are consistent with climate change, i.e., changes to the long term means of the weather variables. For activities that take place at a single location or over a small area (< 100 km), simply varying the inputs is sufficient. If activities take place over larger areas (>100 km) then more sophisticated tools, such as stochastic weather generators may be necessary. An example of such a tool is provided in *Steinschneider and Brown* [2013].

Third, the results of the systematic varying of climate conditions on the performance of the activity is inspected to identify the climate changes that cause the performance to fall below acceptable levels. This may be done visually through the creation of climate response maps. Thresholds that define an “acceptable” level of performance are useful for focusing the analysis on the potential vulnerabilities. The results of the stress test are used to identify vulnerabilities which are then investigated further to assess the level of concern the vulnerabilities pose.

The final report of RC-2204 provides several examples of climate stress tests of varying complexity.

The goal of the climate stress test is to reveal the specific climate conditions that cause the performance of the system to fall below acceptable levels, or “fail.” This is accomplished by systematically varying the weather or climate inputs to a model that simulates performance of the system. The hazards to the system are exhaustively explored and identified by testing a wide variety of possible climate futures. In order to ensure that the climate inputs remain physically meaningful when varied, a stochastic climate and weather generator may be employed. Stated simply, this is a computational algorithm that randomly generates new realizations of weather time series that nevertheless preserve important statistics, such as day-to-day variability and spatial variability, within reasonable historical bounds. However, the mean temperature and precipitation (or other variables as required) are systematically altered to expose the system to climate changes, and in the process, reveal the changes that are problematic.

The climate stress test is conducted using a mathematical representation, i.e., model, of the system that has weather or climate inputs. The weather or climate inputs are then varied to both better understand the sensitivity of the system to climate changes and also to identify the specific climate changes that are problematic. The problematic climate changes are then further assessed to estimate whether they are likely or not to occur, and with this, determine if they pose a significant concern or note. By defining vulnerabilities first, the use of climate science is restricted to the key climate changes that pose vulnerabilities, and assessing their level of concern, rather than attempting to predict a future climate to prepare for. Note that in addition to varying the climate inputs, other uncertain factors can also be varied, and in this way the relative level of concern of climate change in comparison to other important assumptions about the future can be assess.

Note that the range of climate changes tested should encompass the plausible range of climate change, which can be determined quite generally without need for specific analysis. It is recommended that a range of climate change for assessment is prescribed for each geographical region for consistency within the unit or DoD. There are sufficient existing climate databases to quickly determine these ranges with the reviewing authority.

The key to conducting an effective climate stress test for risk assessment is to begin with a clear analytical framework. Box 5 provides a review of framework for collecting and organizing the information needed to design a successful climate stress test that was first presented in Step 2. The four C’s, Consequences, Connections, unCertainties and Choices, are important considerations for structuring the climate stress test and for developing the models needed to conduct the test.

BOX 5 – THE FOUR C'S: FRAMEWORK FOR THE CLIMATE STRESS TEST

A key aspect of the Climate Screening Worksheet is the context analysis which defines the bounds of the system under evaluation. The context analysis is guided by a framework described as the Four C's: **Consequences, Connections, unCertainties and Choices.** This mnemonic serves to establish better understanding of the system itself and the means by which climate risks might be addressed.

Consequences represent the results of a system being negatively impacted by climate change – would it be a temporary inconvenience or a mission damaging impact?

Connections are the links between weather and climate and the system's ability to perform its function. Are there links, are they significant, are they severable?

unCertainties are the external factors that affect the performance of the system. Climate is the prominent factor being assessed, but there may be other uncertain factors that make the lessen the significance of climate uncertainties. For example, underground water pipelines may be affected by climate in some minor ways but the age and material of pipes and the chemical properties of the water are likely more important factors than climate.

Choices represent the decisions that could be made to address any problems that might arise. Identifying and evaluation choices is a part of the climate risk management process but realizing the degree to which a system can be adapted locally through autonomous decisions.

As a means to explore the climate sensitivity of a project, climate response functions may be developed by systematically varying climate conditions and recording changes in performance metrics. A climate response function is simply a function that relates system performance to changes in climate. It is developed using the results of the climate stress test and created as an empirical model as a short cut or model emulator for the full modeling chain used to create it.

Visual representation of the climate response function is a useful way to portray the sensitivities of the system to climate changes, as shown in Figure 5. Figure 5 is an example of a climate response map from RC-2204 assessment of climate change effects on training.

A standard climate response map demonstrates the performance of a system across a wide range of possible climate states. This range of climate space is partitioned into two regions indicated by the green and red colors. The green region indicates the climate changes where system performance is acceptable. In this region, the performance metrics of the system remain above the acceptability threshold for each climate change indicated. The red region indicates that the performance metrics fall below the acceptability threshold for the given climate change. This then defines the climate conditions that cause unacceptable performance of the system.

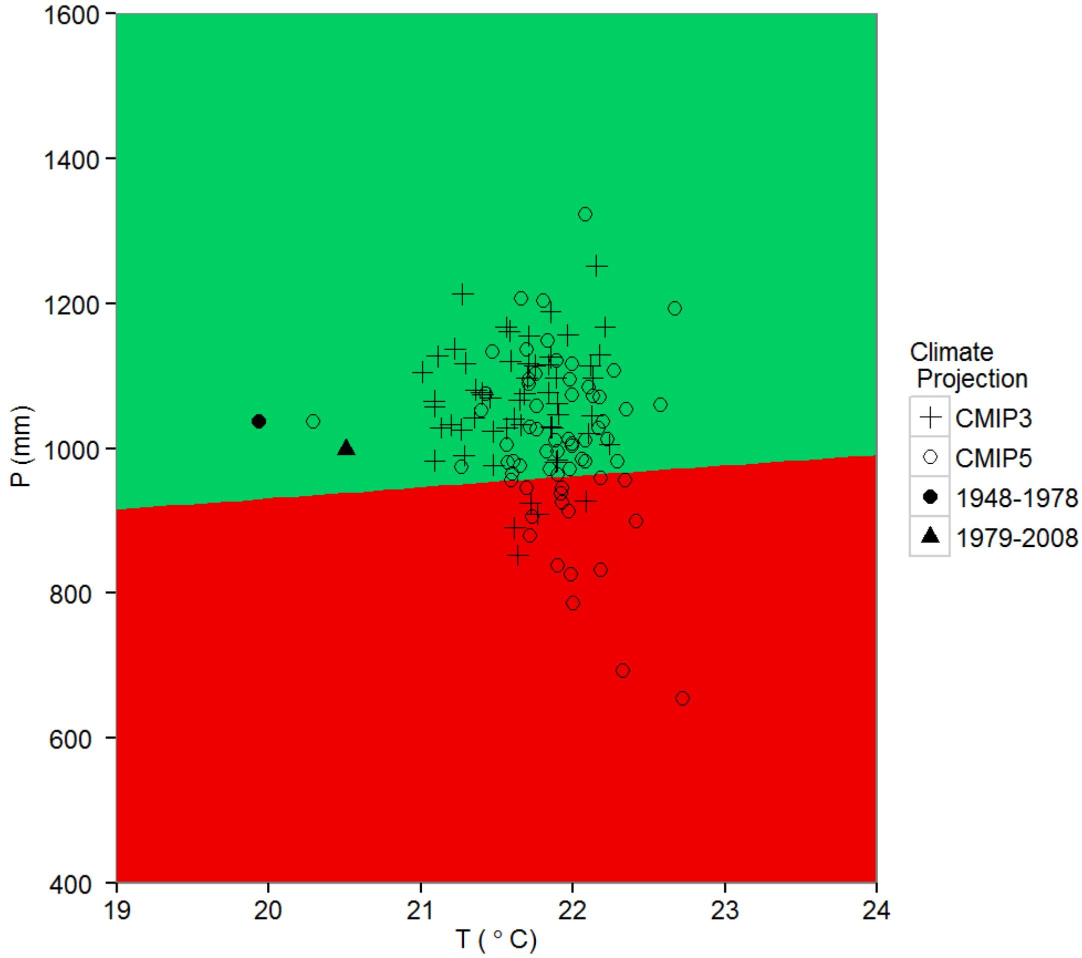

Figure 5. Example climate response map for system showing the kinds of climate changes that cause unacceptable performance (red region) and the climate changes that are not problematic for the system (green area).In this case, the system is much more sensitive to water than to temperature, and decreases in precipitation (roughly less than 900 mm) cause the system to "fail" the climate stress test. In addition, symbols on the surface are used to illustrate the projected climate changes for the system (open circles = CMIP5; crosses = CMIP3). The closed circle and closed diamond show the historical mean climate. .Downscaled GCM values are 20-year averages from 2030-2050.

If no vulnerabilities are revealed on the climate response map, then a Climate Risk Report will explain the process employed and that the activity has been determined to be not at risk from climate change. If the climate response map shows project vulnerabilities within the tested range, then the system performance is determined to be vulnerable to changes in climate. However, that does not yet equate with risk, because risk includes an assessment of the probability that problematic conditions will occur. Estimating that probability is the next step in the risk assessment.

If the activity is shown to be vulnerable to climate then further analysis is required to determine if the problematic conditions are likely or not. This step is a framing of the available climate information in terms of the identified vulnerability that causes negative and "unacceptable" consequences to the activity. Data can be obtained from a wide number of climate data sources, although it is recommended that a specific data set be selected for this purpose. Linking assessment to the data products produced by the National Climate Assessment is logical. The product of consequences and probability of those consequences is our definition of risk. Thus, this represents the risk estimation step.

The evaluation of the risk associated with vulnerabilities identified is carried out by using available data to judge whether the problematic climate conditions are likely, or not, to occur. The approach described here makes the best use of readily available climate information and theory on estimating risks under conditions of climate uncertainty. However, it does not represent an attempt to formally estimate the exact or objective probability of any particular climate change. At present, the best that can be achieved is a subjective, but well-informed judgment of conditions being more or less likely. The method presented here is designed to make that estimation straightforward. This represents a pragmatic and sensible approach to effectively assessing risk.

The probability of the problematic climate conditions identified during the climate stress is accomplished using an information theory approach, where the more information that indicates an event is probable is equated with that event being more probable. In the case of climate change, there are three considerations that lead to the probability determination:

1. Historical occurrence – a particular climate condition is more likely if it has occurred in the past. The more it has occurred in the past, the more likely it is. If there is an increasing trend in the historical record, this means the event will probably be more likely in the future.
2. Scientific Theory – if scientific theory provides solid reasoning for an event to become more likely in the future, then that event is judged to be have higher likelihood in the future.
3. Climate projections – if credible climate projections indicate that an event is going to become more likely in the future, then it is judged to have higher likelihood in the future.

Any one of these sources of probability is not definitive on its own. The more they agree, the more likely they are to be correct. For example, in the case of temperature increases, in most cases the historical record shows clear increasing temperature trends, scientific theory provides solid reasoning for why temperature is likely to increase, and climate projections show temperatures increasing. Therefore, temperature increases should be judged as being very likely and having high probability.

Alternatively, in a particular location precipitation extremes may be observed to be increasing, but that's not true everywhere; scientific theory provides reasoning for why precipitation extremes might increase; climate projections do not have the resolution to simulate precipitation extremes. In this case, increasing precipitation extremes would have medium probability in places where trends have been observed, and low-to-medium probability where they have not been observed. These are simply example judgments; it is ultimately up to the analyst to determine based on the available information.

In addition, the consequences themselves can be usefully brought into the risk estimation. Since the estimation process is necessarily qualitative, there is no ability to multiply probabilities by consequences to determine risk. However, a risk matrix, such as shown in table 1, can be used to achieve the same result in a qualitative framework. Here, high probability and large consequences means that there is high risk. Other combinations are indicated by the table.

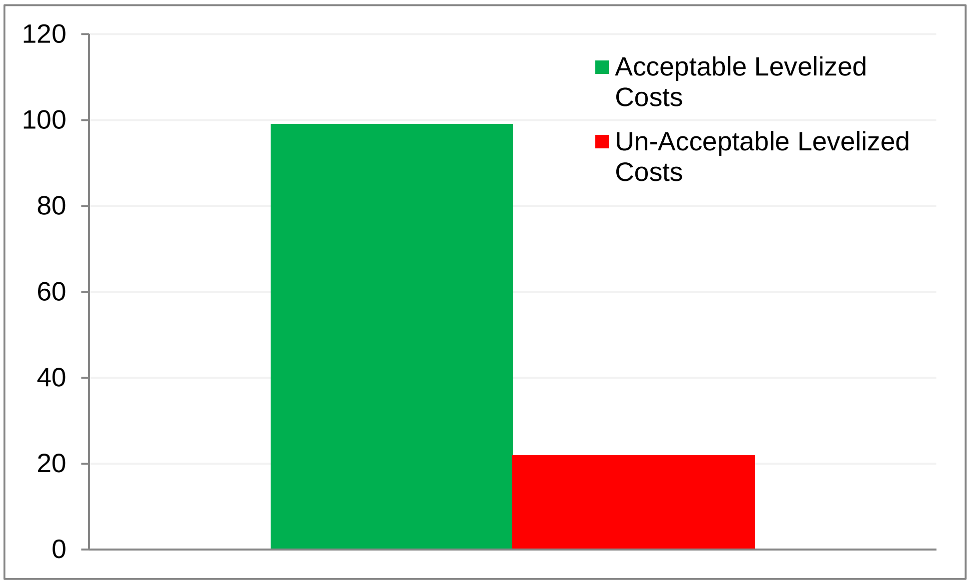

Figure 6. Downscaled GCM count for the climate response map shown in Figure 5.The number of GCM projections indicating acceptable costs indicates that this outcome is more likely according to the projections.

Table 1. Risk matrix

Impact	High impact & Few GCM runs; no historical indication that conditions are possible	High impact & Many GCM runs indicate possibility	High impact & GCM runs and historical record indicate possibility
	Med impact & Few GCM runs; no historical indication that conditions are possible	Med impact & Many GCM runs indicate possibility	Med impact & GCM runs and historical record indicate possibility
	Low impact & Few GCM runs; no historical indication that conditions are possible	Low impact & Many GCM runs indicate possibility	Low impact & GCM runs and historical record indicate possibility
	Probability		

**green indicates low risk and red indicates high risk*

If the risks to the activity performance are very high (i.e., both the historical record and some number of climate projections indicate that the conditions are possible), then this indicates that the activity faces high risk, which is then documented in the climate risk report. . The analysis could proceed to Stage 4 to assess adaptation options, although that is not required. If, however, the impact to the project is in doubt (for example, the project is vulnerable to a climate state indicated by some GCM projections, not to others), an assessment of the credibility of each data source can be conducted before making final conclusions. In case of either a medium probability of impact or a high probability of impact (regardless of the magnitude of impact), it must be asked whether the robustness of the project can be improved.

If the result of the risk matrix is that the impacts are unlikely to occur (for example, there are no projections that indicate the conditions are likely and the conditions have not occurred either historically or in the paleo record) then the Climate Risk Report is completed explaining the climate stress test to which the model of the system was subjected, and presenting the conclusion that detrimental impacts are unlikely to occur.

Stage 3 analysis concludes with the analyst using the results of the analysis to determine whether the climate risks are significant enough that adaptations should be considered. The exact definition of significant climate risks should be defined by the reviewing agency, but it would be logically related to impacts that could impair the ability to perform the missing being somewhat likely. The climate risk assessment concludes with the Climate Risk Report. How that information is used is up to the reviewing agency as their statutory requirements would be complete at that point. The Stage 4 analysis presented next is a possible approach to addressing the significant climate risks if the analysis proceeds to this stage.

Product: **Climate Risk Report** – the report will detail the climate stress test analysis process and the results. The sensitivity of the activity is presented and the risks are discussed in terms of problematic conditions, with the likelihood of those conditions and the impact should they occur. The risk level is determined based on these considerations. climate information sources. Suggested length of 10-20 pages.

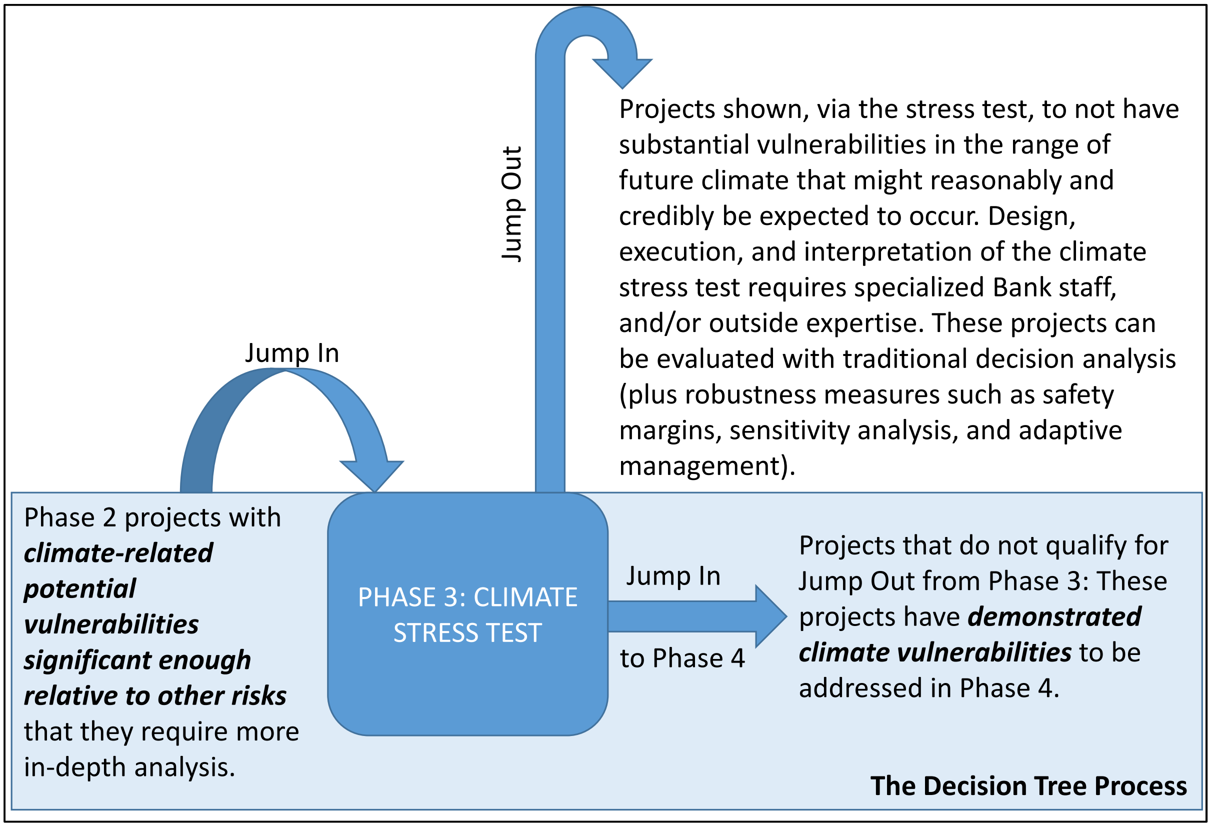

Figure 7. Stage 3 jump-in and jump-out conditions

3.4. Stage 4: Climate Risk Management

In this stage, possible measures for addressing the significant risks identified in Stage 3 are developed and assessed, using traditional planning approaches as well as the analytical assessment approach presented in Stage 3. That analysis is repeated for promising options to assess their effectiveness in reducing the climate risks previously identified in the initial Climate Risk Report.

The development of climate risk management approaches extends beyond the scope of the risk assessment process but is natural to proceed from identifying risks to developing plans to address them. While traditional planning tools like Benefit Cost Analysis remain essential to evaluating options to address climate risks, special considerations for the use of probabilities in those methods should be considered. There are a number of approaches to addressing uncertainty in decision making processes in addition to the methodology that has been described in this document. Box 6 describes the uncertainty conditions where these methods are most helpful.

BOX 6 – DEEP AND SEVERE UNCERTAINTY

Deep uncertainty refers to the condition in which probability distributions cannot be assigned to the key uncertainties, the appropriate models to describe interactions among a system's variables are lacking, and/or the relative desirability of various alternative outcomes cannot be quantified.

Severe uncertainty refers to conditions in which an unbreachable disparity exists between what is known and what needs to be known to make a dependable decision.

For the purpose of decision making under uncertainty, the common thread between the two concepts is that they elude characterization by a probability distribution.

Hallegatte et al. [2012] provide a summary of four categories of planning tools that have been used for this purpose: Cost Benefit Analysis (CBA) under Uncertainty [e.g., *Arrow et al.*, 1996], real options analysis (RO) [e.g., *Arrow and Fisher*, 1974; *Henry*, 1974; *Ranger et al.*, 2010], Robust Decision Making (RDM) [e.g., *Lempert and Schlesinger*, 2000; *Lempert et al.*, 2006], and decision-scaling, as discussed throughout this paper. Section 7.4 of the full Decision Tree Document expands on those options, adding IGDT [*Ben-Haim*, 2006], stochastic optimization [*Loucks et al.*, 1981] and multi-objective robust optimization [*Mulvey et al.*, 1995; *Ray et al.*, 2014; *Watkins and McKinney*, 1997] to the suggested techniques for decision making under uncertainty. Multi-objective robust optimization and many-objective optimization [*Kasprzyk et al.*, 2013; *Reed and Minsker*, 2004] are sister techniques, and ideologically the same. In addition, safety margins may play important roles in decision making under uncertainty and can be evaluated using the methods described in this guide. Box 7 describes some attributes that are beneficial for managing uncertainty.

BOX 7 – ROBUSTNESS AND ADAPTABILITY/FLEXIBILITY

Robust project designs perform reasonably well compared to the alternatives over a wide range of plausible futures. The robustness of any initial decision can be expressed as a function of the number of possible futures (or size of the projected future domain) with which it is compatible divided by the total number of projected futures (or total size of the projected future domain). A system fitting this definition might be described as being "reliable" over a wide range of plausible futures, or possibly, depending upon context, as having relatively low vulnerability.

Adaptability/Flexibility is preferable when (1) uncertainty is more "dynamic" than "deep" – our knowledge improves over time; and (2) the project involves irreversible creation or destruction of capabilities. Certain adaptation strategies are more flexible than others to the possibility of upgrade in the future in the event that impacts of climate change are high. Real options analysis is an established probabilistic decision process by which adaptability can be explicitly incorporated into project designs, and large potential regrets associated with either over-investment or under-investment in adaptation measures can be avoided. Real options analysis encourages staged decision making through which more expensive and more highly-irreversible decisions are reserved until more information is available on which to base those decisions.

Techniques that emphasize optimality are not recommended for decision making under uncertainty. Rather, techniques that aim at robustness to a wide range of futures [*Brown and Wilby*, 2012; *Kasprzyk et al.*, 2013; *Lempert et al.*, 2006; *Prudhomme et al.*, 2010; *Ray et al.*, 2014; *Wilby and Dessai*, 2010] or adaptive management techniques such as real options that add flexibility to incrementally adapt to a wide range of futures [*Adger et al.*, 2005; *HM Treasury and Department for Environment, Food and Rural Affairs*, 2009; *Jeuland and Whittington*, 2013; *Ranger et al.*, 2010] are preferred. *Rosenhead* [1989] describes robustness as a particular perspective on flexibility. Robustness and adaptability are not mutually-exclusive goals, and the best water systems plans will incorporate elements of both, but as initial strategies to model development, they are founded on slightly different premises. Techniques that aim at robustness skew toward the conservative, as they seek solutions that perform satisfactorily even in unknown future conditions significantly worse than the expected. Techniques that emphasize adaptability do not necessarily recommend options that perform satisfactorily in the worst case, but hold open the ability to adjust if it begins to look like the worst case is more likely.

Product: **Climate Risk Management Plan** – an assessment that reaches Stage 4 will have considerable climate vulnerabilities that must be addressed. Each risk management plan will be unique to the activity considered but should likely consist of components of both adaptability/flexibility and robustness. The plan should detail the climate risks faced, and the means to address those risks. In some cases, the risks may be judged by consulted experts to be acceptable without taking additional steps. In other cases, adjustments may be proposed to ensure that the occurrence of certain climate conditions does not cause the activity to fail in its objectives. The length of the report varies, but likely requires more than 20 pages of analysis.

The Climate Risk Report is completed only in the event of jump-out from Stage 3. However, the goal of the **decision tree** is to achieve project designs with low vulnerabilities (high robustness) to climate change. Therefore, projects modified in Stage 4 (unless they are abandoned during Stage 4) are resubmitted to a Stage 3 climate stress test. If the Stage 4 design modifications were sufficient to successfully pass the project out of the **decision tree** through Stage 3, then a Climate Risk Management Plan is included as part of the Climate Risk Report.

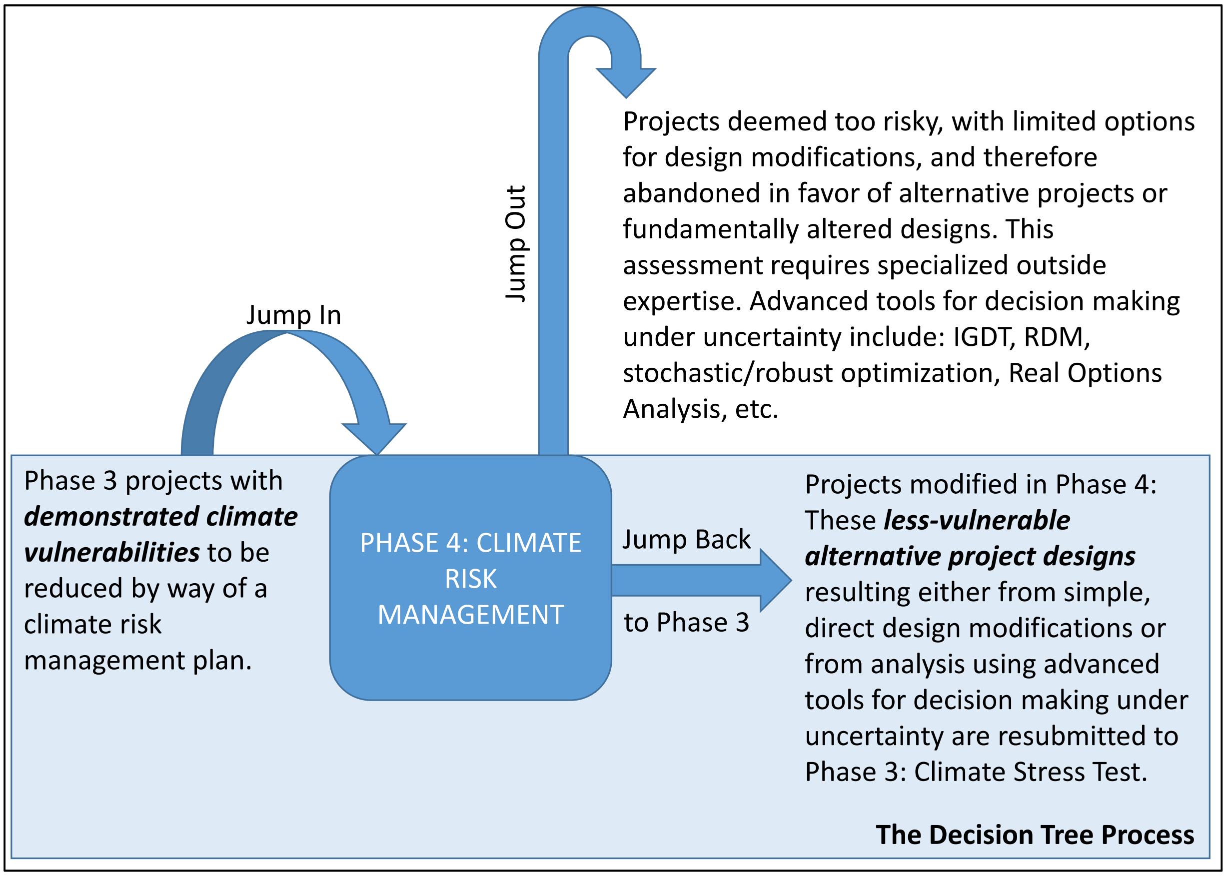

Figure 8. Stage 4 jump-in and jump-out conditions

4. CONCLUDING REMARKS

This document describes a basic framework for assessing climate risks to DoD installations. The framework is based on insights drawn from RC-2204 and more generally from the decision-scaling concept, decision making under uncertainty and climate science. Decision-scaling is a bottom-up, robustness-based approach to climate risk assessment and management that makes use of climate stress testing for the identification of vulnerabilities, and simple, direct techniques for the iterative reduction of vulnerabilities through targeted modifications. The framework adapts these methods to create an efficient and effective staged approach to assessing climate risks.

Recognizing that different activities require different levels of effort for assessment, the framework uses a staged approach, where the analytical effort is proportional to the level of concern. The process is hierarchical with different stages or stages triggered based on the findings of the previous stage. The **Climate Risk Assessment Framework** consists of four successive stages: Stage 1 Climate Risk Screening; Stage 2 Climate Sensitivity Test; Stage 3 Climate Stress Assessment; and Stage 4 Climate Risk Management. The result is different categories of projects that undergo different types of analysis with effort that is proportionate to the need.

The process described in this guide is a framework and serves as a model for developing more tailored processes for a particular service, agency or other organization. In addition, the process will require access to information sources and in some cases analytical ability to complete. Finally, training would likely be necessary for analysts to complete the process in not already familiar with the techniques employed.

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